Research paper / Оригинальная статья
https://doi.org/10.51176/1997-9967-2025-1-90-102
МРНТИ 67.09.29
JEL: Q53, Q56, R11

The Impact of Urbanization on Greenhouse Gas Emissions: A Multidimensional Analysis

Makpal S. Bekturganova[a]*

[a]*Institute of Economics CS MSHE RK, 28 Shevchenko Str., A25K1B0, Almaty, Kazakhstan*

For citation: Bekturganova, M. S. (2025). The Impact of Urbanization on Greenhouse Gas Emissions: A Multidimensional Analysis. Economy: strategy and practice, 20(1), 90-102, https://doi.org/10.51176/1997-9967-2025-1-90-102

ABSTRACT

Today, urban areas are considered significant sources of CO_2 emissions, making the problem of climate change particularly urgent. This study aims to analyze urbanization's impact on greenhouse gas emissions, identify key economic, social, and environmental factors, and propose recommendations for sustainable urban development. The study is based on econometric analysis of panel data collected from 107 countries from 2004 to 2023 from the World Development Indicators (WDI) database, using linear regression models to examine the relationship between urbanization levels and CO_2 emissions. Results show a negative correlation (-0.361) between urbanization and emissions, indicating the potential for reducing emissions through compact urban development, with energy consumption as the main factor contributing to increased emissions (R^2 = 0.8541). Renewable energy use has a significant effect on reducing emissions (-0.585). In Kazakhstan, high dependence on coal-fired power leads to an increase in emissions. However, an increase in the share of renewable energy sources can significantly improve the environmental situation (-0.830). Thus, the results of the study confirm that urbanization, provided by compact urban planning and the introduction of renewable energy, can contribute to reducing CO_2 emissions per capita. It is advisable to study specific future strategies for reducing emissions in Kazakhstan, including developing smart cities and low-carbon technology. The work has practical value, offering recommendations on integrating sustainable energy use, efficient infrastructure, and environmental management into Kazakhstan's urbanization process.

KEYWORDS: Economy, Green Economy, Sustainability, Sustainable Development, Urbanization, Urban Areas, Emissions, Renewable Energy

CONFLICT OF INTEREST: the author declare that there is no conflict of interest

FINANCIAL SUPPORT: This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant «Exploring the impact of economic, social, and environmental factors on the relationship between urbanization and greenhouse gas emissions» No. AP19576071).

Article history:
Received 10 September 2024
Accepted 17 February 2025
Published 30 March 2025

* **Corresponding author: Bekturganova M.S.** – PhD, Leading Researcher, Institute of Economics CS MSHE RK, 28 Shevchenko Str., Almaty, Kazakhstan, 87013752114, email: maka_91@inbox.ru

Влияние урбанизации на выбросы парниковых газов: комплексный анализ

Бектурганова М.С.[a]*

[a]*Институт экономики КН МНВО РК, ул. Шевченко 28, A25K1B0, Алматы, Казахстан*

Для цитирования: Бектурганова М.С. (2025). Влияние урбанизации на выбросы парниковых газов: комплексный анализ. Экономика: стратегия и практика, 20(1), 90-102, https://doi.org/10.51176/1997-9967-2025-1-90-102

АННОТАЦИЯ

Сегодня городские районы считаются значительными источниками выбросов CO_2, что делает проблему замедления изменения климата особенно актуальной. Цель исследования - провести анализ влияния урбанизации на выбросы парниковых газов выявляя ключевые экономические, социальные и экологические факторы, а также предложить рекомендации для устойчивого развития городов. Исследование основано на эконометрическом анализе панельных данных 107 стран за 2004-2023 гг., собранных из базы Всемирного банка (WDI). В работе используются линейные регрессионные модели для изучения связи между уровнем урбанизации и выбросами CO_2. Полученные результаты показывают, что существует отрицательная корреляция между урбанизацией и выбросами CO_2 (-0.361), что указывает на возможность снижения выбросов при компактном развитии городов. Основным фактором увеличения выбросов является потребление энергии ($R^2 = 0.8541$). Использование возобновляемых источников энергии оказывает значительное влияние на снижение выбросов CO_2 (-0.585). В Казахстане высокая зависимость от угольной энергетики приводит к росту выбросов, однако увеличение доли возобновляемых источников энергии (-0.830) может значительно улучшить экологическую ситуацию. Таким образом, результаты исследования подтверждают, что урбанизация, при условии компактного городского планирования и внедрения возобновляемых источников энергии, может способствовать снижению выбросов CO_2 на душу населения. В дальнейшем целесообразно изучить конкретные стратегии снижения выбросов, применимые к Казахстану, включая развитие умных городов и внедрение низкоуглеродных технологий. Работа имеет практическую ценность, предлагая рекомендации по интеграции устойчивого использования энергии, эффективной инфраструктуры и экологического управления в процесс урбанизации Казахстана.

КЛЮЧЕВЫЕ СЛОВА: экономика, зеленая экономика, устойчивость, устойчивое развитие, урбанизация, городские районы, выбросы, возобновляемые источники энергии

КОНФЛИКТ ИНТЕРЕСОВ: автор заявляет, что отсутствует конфликт интересов

ФИНАНСИРОВАНИЕ: статья подготовлена в рамках проекта грантового финансирования Комитета науки Министерства науки и высшего образования «Исследование влияния экономических, социальных и экологических факторов на взаимосвязь между урбанизацией и выбросами парниковых газов» AP19576071.

История статьи:
Получено 10 сентября 2024
Принято 17 февраля 2025
Опубликовано 30 марта 2025

* **Корреспондирующий автор: Бектурганова М.С.** – PhD, ведущий научный сотрудник, Институт экономики КН МНВО РК, ул. Шевченко 28, Алматы, Казахстан, 87013752114, email: maka_91@inbox.ru

INTRODUCTION

The increasing pace of urbanization and the immediate necessity for slowing down climate change have made the urbanization - GHG emissions nexus an important research topic worldwide. Hydrogen particles are mostly labeled greenhouse gases because carbon dioxide (CO2) is one of the most critical greenhouse gases. So, in this paper, CO2 and greenhouse gas (GHG) will be used synonymously to refer to carbon dioxide emissions per capita. Truthfully, urban areas have been seen as significant contributors to carbon dioxide (CO_2) emissions, ascribing their important role to growth and modernization. Indeed, it shall be noted that recent studies have also shown how urbanization could lower CO2 emissions via the combination of sustainable policies with effective urban planning. The case of Kazakhstan is interesting in the investigation of these dynamics and the definition of policy options for balancing environmental sustainability and urban growth since it is a developing country that is rapidly urbanizing.

The relationship between urbanization and CO2 emissions has been extensively researched over time, with competing perspectives. One such case is Dodman (2009) and Glaeser and Kahn (2010), wherein they noted that effective urban systems would contribute to the per capita reduction of emissions in advanced economies. Instead, Shahbaz et al. (2016) reported augmenting emissions in developing countries due to poor infrastructure and dependency on fossil fuels for energy consumption. Despite these differences, we understand very little about the underlying relationship between urbanization and emissions as it is being fashioned through a social, economic, and environmental prism. Even the complex link in Central Asia - the contemporary case of Kazakhstan, with its peculiar economic structure, energy policy, and urbanization trajectory- could be poorly placed. It is imperative to bridge the gap so that some theoretical advancements can be made that would later translate into practices for solving sustainable urban development issues.

This research is particularly relevant in the context of the global agenda to achieve the United Nations' Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action). Urbanization and its associated energy demands, for example, remain one of the barriers to a nation's fulfillment of its international climate obligations, such as those contained in the Paris Agreement. The study holds particular relevance for Kazakhstan, where fossil fuel dependence is high and urbanization is increasing. The analysis aims to determine the determinants of urbanization-CO_2 emission relationships, which is important in formulating effective policies compatible with the economic and social objectives of the country and with the international environmental aspirator.

This study examines how economic, social, and environmental factors influence the link between urbanization and CO_2 emissions. Given the growing global demand to balance urban development and environmental sustainability, it is essential to identify the conditions under which urbanization can mitigate rather than exacerbate carbon emissions. The research employs statistical and econometric techniques to analyze urban growth and CO_2 emissions across 107 countries from 2004 to 2023 to achieve this. Key variables include urban population growth, industrial activity, energy use, renewable energy consumption, population density, and urban air pollution. The study applies descriptive statistics, correlation methods, and linear regression models to examine the relationship between urbanization and carbon emissions. A key hypothesis is that CO_2 emissions per capita can be reduced under specific conditions, such as compact urban development and increased use of renewable energy.

This research addresses the fundamental question:

"Does urbanization foster or slow down greenhouse gas emissions?" Through a quantitative econometric approach, the study provides empirical evidence to inform policymakers and support the development of effective strategies for reducing CO_2 emissions.

Research objective:

This paper aims to analyze the impact of urbanization on greenhouse gas emissions, identify key economic, social, and environmental factors, and propose recommendations for sustainable urban development. To achieve this, the study aims to: (1) analyze the relationship between urban growth and CO_2 emissions using econometric techniques on a global dataset; (2) identify the environmental, social, and economic determinants affecting this relationship; (3) examine the urbanization-CO_2 emissions link in Kazakhstan; (4) develop policy recommendations based on empirical findings.

This research contributes to the ongoing discourse on urbanization and sustainability, providing valuable insights for policymakers and researchers seeking to align urban expansion with climate goals. Additionally, it highlights the role of sustainable urban planning, energy transition strategies, and innovative policy instruments in shaping low-carbon urbanization pathways, particularly in developing economies such as Kazakhstan.

LITERATURE REVIEW

Urbanization is one of the most significant developments of the 21st century, and indeed, there have been many advantages and disadvantages attached to urbanization with economic progress. Urbanization has been an active stimulus for economic growth. It has contributed to greenhouse gas (GHG) emissions due to increased energy consumption, demand for transport, and industrial activity. It is, therefore, essential to understand the economic processes of urbanization to mitigate their environmental impacts and thrive economically (Sufyanullah et al., 2022). Recently, these links have been studied, emphasizing how economic variables influence emissions vis-à-vis urbanization.

According to Seto et al. (2012), industrialization is a prominent economic force driving urbanization. People move to urban centers for a better life as industries grow, creating job opportunities. In this study, strongly economically developed cities tend to grow much faster since those cities make lifestyles much better and provide easy access to basic amenities around them. For people constrained in rural living, portraying access to available jobs in cities, very much is one major pull factor for migration from rural settings where economic opportunities are sometimes extremely poor (Liu et al., 2020). The quality of life in cities is improved through investments such as housing, public utilities, and transportation networks, which draw even more individuals into the urbanization trend (Glaeser & Kahn, 2010).

Urbanization challenges have been borne out of the same economic forces that have mobilized the progressive urban environmental problems as rising emissions. About 70% of the world's energy is consumed in urban areas, primarily from fossil fuels for heating, cooling, and electricity, which significantly raises emissions on a global level (IEA, 2021). With the increase in urbanized population and enhanced energy needs, there is a corresponding increase in environmental load. Since most urban growth results in increased dependence on privately owned vehicles, it is also a key area where emissions have been due to transportation. Poor public transport systems within cities have resulted in a high per capita carbon footprint among the cities (Creutzig et al., 2015). The activities concerning industries and construction related to urban growth also worsen this issue. Steel and cement production, not to mention land-use changes at a large scale, increases the carbon footprint of growing metropolitan areas (Weigert et al., 2022).

Urbanization and greenhouse gas emissions share some twisted relationship through many interrelated dimensions. Evolving consumption habits on the back of economic development in cities usually worsen the level of emissions. Urbanization has also been affected by differences in socioeconomic levels among populations. Especially among the poor, poor air quality and infrastructure generally constitute the most significant part of the environmental burden on vulnerable populations (Seto et al., 2012). Thus, it is necessary to examine realistic alternatives that would remove or reduce the adverse effects of urbanization on the environment without compromising economic development on such a scale.

Changing energy sources to cleaner ones and increasing urban energy efficiency remain the primary strategies for emission reduction. Such a shift brings emissions down to an astonishing level while ensuring sustainable development (UN-Habitat, 2020). Lastly, urban planning has traditionally played a significant role in establishing sustainable cities. Municipalities designed in a compact manner in combination with green spaces, diversified land use management, and efficient resource management may help promote environmentally sustainable trends in urbanization (Glaeser & Kahn, 2010).

Kazakhstan is an impressive example of the successful linkage between urbanization, economic growth, and environmental sustainability. The share of the urban population increased from 51% in 2000 to over 58% in 2020, with about half of the increase occurring in the last 20 years. This process is closely related to the economies, especially in the industrial and energy sectors, which significantly contribute to greenhouse gas emissions (Bekturganova & Kireyeva, 2024). High shares of coal (around 70% in its energy mix), together with other aspects, have made the energy architecture highly dependent, high-emitting, and deteriorating in terms of air quality. City life in places like Astana and Almaty regularly suffers from less-than-ideal air quality due to high levels of particulate matter when measured against WHO criterion standards (Bekbossinova & Niyazbekov, 2024).

Kazakhstan's urbanization, energy production, infrastructure development, and industrial growth have, in large measures, molded the nation into shape. The fossil fuel sector is of national importance to spur the economy as it drives urbanization and, consequently, energy consumption. However, environmental and urban expansion effects have worsened with outdated technologies and inefficient industrial processes (Raihan & Tuspekova, 2022; Wang et al., 2019). Although the high mobility in cities is increasing transport emissions, poor mobility at different times remains one of the primary sources of urban air pollution because the number of cars is increasing, especially in places like Almaty, spiking dramatically emissions (Bekturganova & Kireyeva, 2024; Tleppayev et al., 2023). It is evidence that, on average, if Almaty's economic activity increases by 10%, pollution concentrations will increase by 5% (Bekbossinova & Niyazbekov, 2024).

Kazakhstan has formulated policies and regulations for emission reductions and sustainable urbanization to mitigate them. The Strategic Development Plan envisages, among other things, reducing greenhouse gas emissions by 15% by 2025 and increasing the share of renewable energy in power generation by 10% (Bekturganova & Kireyeva, 2024). Through initiatives to advance compact urban planning, invest in green infrastructures, and shift to cleaner energy sources, they believe a more sustainable future is enjoyed in urbanism (Raihan & Tuspekova, 2022).

Kazakhstan's urbanization trajectory highlights the delicate balance between economic growth and environmental sustainability. While urban expansion contributes to economic prosperity, it also exacerbates sustainability challenges. The future of Kazakhstan's urban development depends on the successful implementation of policies that align economic growth with climate commitments. Achieving this balance will require a combination of policy innovation, technological advancements, and regional adaptation strategies to ensure that urban development does not come at the cost of environmental degradation.

An analysis of the literature shows that the impact of urbanization on greenhouse gas emissions is ambiguous and depends on many factors. Several studies have confirmed that in countries with a high dependence on fossil fuels and an underdeveloped infrastructure, urbanization leads to an increase in CO2 emissions. This is due to the growth of industrial activity, energy consumption, and transport emissions, which are typical of Kazakhstan, where coal's high share in the energy mix exacerbates the environmental situation. However, research has also noted that the impact of urbanization on emissions can vary depending on the level of urban infrastructure development, technological progress, and economic transformation. In countries where sustainable technologies and efficient transportation systems are actively being developed, cities can become energy-efficient centers and contribute to reduced emissions. In Kazakhstan, despite the growing environmental challenges, there is potential for improvement through introducing low-carbon technologies, industrial modernization, and the development of smart cities. This makes further research in this area particularly relevant, as it can contribute to developing strategies that minimize the adverse effects of urbanization without prejudice to economic development.

RESEARCH METHODS

This study employs a multidimensional analysis to examine the relationship between urbanization and CO_2 emissions, incorporating economic, social, and environmental dimensions. Previous research has established that urbanization's impact on emissions is complex and depends on various factors such as industrialization, energy consumption, and policy frameworks. The research builds on the Environmental Kuznets Curve hypothesis (Grossman & Krueger, 1995), which suggests that emissions initially rise with economic growth but later decline as economies transition to cleaner technologies. However, the impact of urbanization on emissions remains complex, as it is influenced by energy sources, economic structures, and regulatory frameworks (Zhang & Lin, 2012).

Higher energy consumption, more industrial activities, and more extensive infrastructures are some ways urbanization can elevate emissions (Shahbaz et al., 2016). However, urbanization can also increase energy efficiency, public transport, and economies of scale in energy consumption (Seto et al., 2014). Assessing the involvement of economic, social, and environmental issues is essential because the net effect is determined by how sustainably urban growth is managed. Incorporating how urbanization affects CO2 emissions with significant economic, social, and environmental factors, this research adds to the existing body of literature. Previous studies claim that CO_2 emissions are primarily associated with industry (Wang et al., 2016), energy consumption, and air pollution (Ding et al., 2020). Renewable energy is critical in emission reduction, but that largely depends on legislation mode and financial incentives (Apergis & Payne, 2010).

The research implements multidimensional analysis to examine the relationship between urbanization and CO_2 emissions through the economic, social, and environmental dimensions. Because urbanization produces a more complex relationship with emissions, a one-dimensional approach is insufficient to capture many interacting factors in the emissions levels. Hence, the present research adopts a framework for understanding the relationship by studying several indicators simultaneously, creating a complete framework that produces a more refined evaluation of how urbanization interacts with economic growth, energy consumption, human population dynamics, and environmental sustainability.

To achieve a refined evaluation of how urbanization interacts with economic growth, energy consumption, human population dynamics, and environmental sustainability, the study follows a five-stage research design, as shown in Figure 1.

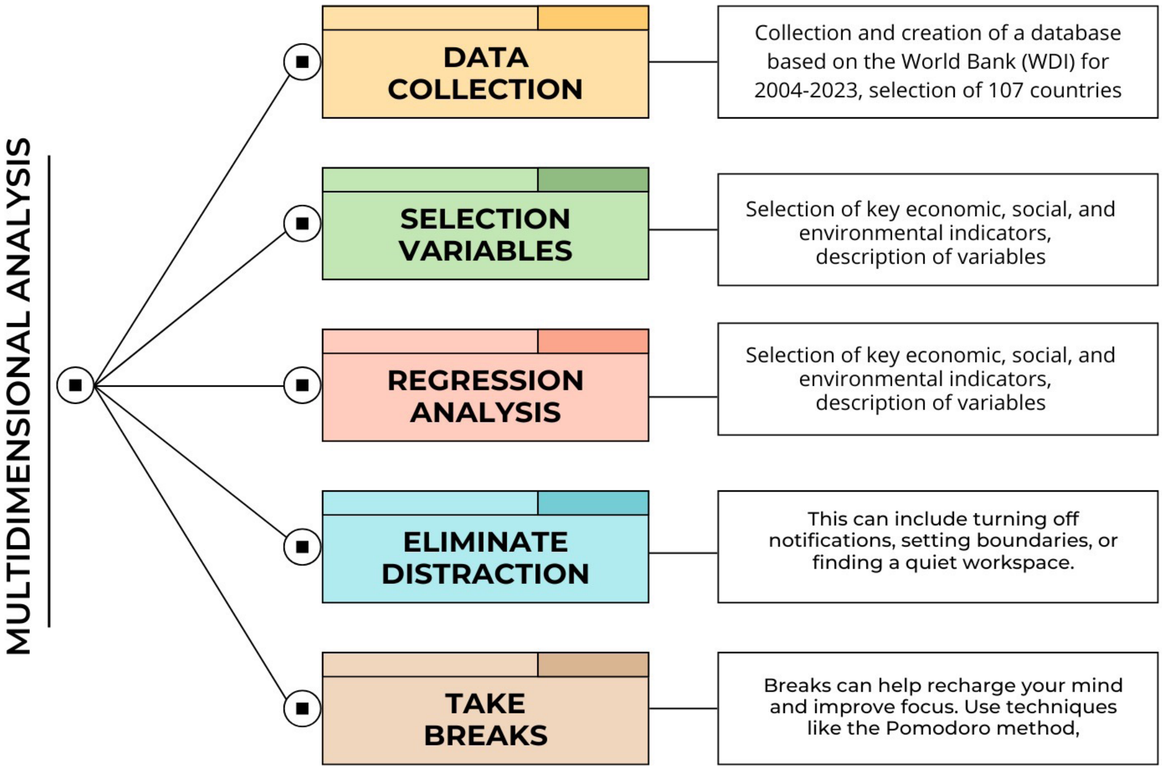

Figure 1. The main stages for conducting multidimensional analysis

First, the current study will collect and preprocess data to have it comparable and consistent across countries. The panel data include sources covering 107 countries from 2004 up to 2023 from the World Development Indicators (WDI) of the World Bank. Countries are selected based on data availability for significant economic, social, and environmental dimension variables relevant to urbanization and/or emissions. Kazakhstan has also been given special consideration as a case study to investigate any deviation from global trends. The data undergoes cleaning and transformation processes to alleviate missing values and ensure comparability.

The second step is defining and categorizing the key parameters into economic, environmental, and social dimensions. Consumption of energy per capita, industrial value-added, and so on constitute the economic parameters directly impacting CO_2 emissions. The following two relate to the environment: PM2.5 (an indirect measure of air pollution) and percentage share of renewable energy, permitting an evaluation of the role of cleaner sources in mitigation. These variables are social indicators of urban population density and the share of the population found in the largest city, hence capturing space distribution and urban concentration movement.

Regression analysis will be the third stage. A series of linear regression models will be estimated using the ordinary least squares (OLS) method. The main goal of the analysis will be to assess the impact of urbanization on per capita CO_2 emissions whilst taking various other factors into control. Regressions are conducted separately for individual indicators, followed by a combined model taking up all three dimensions. At the same time, interaction terms are included to see whether the effect of urbanization is dependent on factors like energy consumption, industrialization, or renewable energy uptake. Models' statistics will be evaluated using R-squared values and p-values.

The fourth step consists of a comparison concerning the global trends with the specific case of Kazakhstan. This is intended to construct correlation matrices and regression exercises individually within the premises of Kazakhstan. A country exhibits different symptoms from those averaged across the globe. This becomes vital considering that Kazakhstan vastly banked on fossil fuels and is speeding through urbanization, thus generating particular drivers of emissions that strongly diverge from global trends.

Lastly, interpreting results and policy recommendations form the final step of multidimensional analysis. For instance, whether urbanization results in increased or decreased emissions under different scenarios is analyzed in the light of sustainable urban development. Policy recommendations will thus emanate from the empirical findings highlighting, for example, strategies of compact city planning, energy efficiency improvements, expansion of renewable energy infrastructure, and enhanced public transportation systems. Such policies are highly relevant for sustainable development and the achievement of national climate policies in tandem with the urbanization trajectories of Kazakhstan.

Hence, through this multidimensional approach, the study goes beyond the simplistic models of urbanization-emissions relation and offers a much more integrated view of how urban growth can be managed vis-a-vis environmental sustainability. It ensures that urbanization is not merely construed as a cause of emissions but also potentially an avenue for their reduction, given the policy environment and urban planning strategies in place.

Including economic and social environmental aspects in a fully complete panel data analysis, this research improves the empirical comprehension of how changes in urbanization affect CO_2 emissions. Unlike several studies focusing only on industrialization or economic growth, this study goes beyond measuring pollution levels and trends in urbanization to renewable energy usage, thus providing a comprehensive view. The evidence-derived policy recommendations based on the findings will be of significant importance to Kazakhstan, among which are energy transition priorities and a sustainable urban development agenda.

ANALYSIS AND RESULTS

The results indicate that while population density (PD) exhibits the most variation, economic indicators such as population in the largest city (LC) and industrial value added (IND) are relatively stable. Notably, there is a moderate to high variation in energy use per capita (EUPC) and carbon emissions (CO_2), which may be connected to differences in industrialisation levels, energy restrictions, and the use of renewable energy in various countries. Although urbanization patterns vary in each country, they typically follow a similar pattern, according to the moderate dispersion of urban growth (URB).

The summary descriptive statistics of 107 countries from 2004 to 2023 of the major variables used in the regression models are shown in Table 1.

Table 1. Descriptive statistics of the panel data variables

	No. of observations	Mean	Std	Min	Max	Coefficient of Variation
URB	1313	1.784	1.674	-8.625	10.516	0.938
IND	1313	28.908	11.032	9.435	86.670	0.382
EUPC	1313	2101.180	1817.287	112.685	8456.036	0.865
RE	1313	28.846	26.580	0.000	98.000	0.921
PD	1313	172.205	658.068	1.595	7714.702	3.821
LC	1313	28.984	15.455	3.066	100.000	0.533
PM25	1313	25.371	14.745	5.625	90.968	0.581
CO2	1313	4.988	4.523	0.039	20.697	0.907

Note – compiled by the author

In order to analyse the relationships between the key variables, Table 2 displays the correlation coefficients between urbanization (URB), industrialization (IND), energy use per capita (EUPC), renewable energy consumption (RE), population density (PD), population concentration in the largest city (LC), air pollution (PM25), and carbon dioxide emissions per capita (CO2). Thus, the correlation matrix of the variables is shown in Table 2.

Table 2. The correlation coefficient of the variables used in the regression model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
URB	1							
IND	0.222	1						
EUPC	-0.362	0.034	1					
RE	0.434	-0.142	-0.459	1				
PD	0.022	-0.050	0.162	-0.123	1			
LC	0.098	0.001	-0.202	0.163	0.405	1		
PM25	0.369	0.183	-0.431	0.240	-0.058	-0.066	1	
CO2	-0.361	0.092	0.924	-0.585	0.098	-0.220	-0.354	1

Note: compiled by the author

The correlation matrix shows that urbanization is positively correlated with air pollution (PM2.5) (0.369). However, interestingly, there is a negative correlation (-0.361) between urbanization and CO_2 emissions, indicating that urbanization under control can lower emissions per capita.

The substantial correlation between energy uses per capita (EUPC) and CO_2 emissions (0.924) supports the idea that emissions are driven by greater energy use. At the same time, CO2 has a negative correlation (-0.459) with renewable energy, which is expected, suggesting that economies that rely on fossil fuels consume less clean energy. The significant inverse relationship between renewable energy (RE) and CO_2 (-0.585) supports RE's contribution to emissions reduction. Air pollution (0.183) and CO_2 (0.092) have a weak correlation with industrialisation (IND), indicating that the impact of IND varies depending on the energy sources used. Urban concentration and population density (PD) have a moderate correlation (0.405), although PD has little effect on CO2 (0.098).

These results demonstrate that energy usage is the primary source of emissions, that urbanization can reduce CO_2 emissions if handled well, and that using renewable energy is essential to lowering carbon footprints.

While the coefficient values illustrate the direction and strength of the link, the R-squared values demonstrate how much of the variation in CO_2 emissions can be explained by each variable alone. The p-values and significance levels indicate the statistical importance of the correlations.

The findings of simple linear regressions, in which each independent variable is regressed independently on CO2 emissions per capita, are shown in Table 3.

Table 3. Linear regression of every variable to CO2 emission

Variable	R-squared	Coefficient	P-value	Significance
URB	0.1304	-0.976	9.81E-42	***
IND	0.0084	0.0375	0.000895	***
EUPC	0.8541	0.0023	0	***
RE	0.3421	-0.0995	2.28E-121	***
PD	0.0097	0.0007	0.000351	***
LC	0.0483	-0.0643	7.71E-16	***
PM25	0.1252	-0.1085	5.23E-40	***

Note: compiled by the author

In the above-shown Table 3, linear regression urbanization (URB) has a negative and substantial influence on CO_2 emissions (-0.976, $p < 0.001$), suggesting that as urbanization increases, per capita emissions decrease. The fitted linear regression models are represented by the red lines, which aid in visualising the patterns and degree of correlation.

Energy consumption per capita (EUPC) is the most accurate measure of CO2 emissions (R2 = 0.8541). The scatter plot's clear upward trend (coefficient: 0.0023) illustrates how substantially increasing energy usage affects emissions. The use of renewable energy (RE) has a considerable negative impact on CO2 emissions (-0.0995, $p < 0.001$). The scatter plot's downward trend highlights how crucial it is to boost the usage of renewable energy to reduce emissions, as renewables account for 34% of the variance in CO2 (R2 = 0.3421). CO_2 emissions have a negative correlation with air pollution (PM2.5) (-0.1085, $p < 0.001$). This could result from more stringent environmental laws in countries with more significant CO2 emissions, which would lower air pollution.

The tiny upward trend in its scatter plot indicates that the IND has a small but beneficial effect on CO_2 emissions (0.0375, $p < 0.01$). However, it only accounts for 0.8% of the variation in CO_2, indicating that the impact of industrialization is dependent on energy efficiency and use. Population in the largest city (LC) and population density (PD) have a small but noticeable impact on CO2 emissions. A modest negative correlation is seen with higher urban concentration (LC, -0.0643), indicating that more centralized urbanization may result in improved energy efficiency and infrastructure use. The scatter plots demonstrate that energy use is the primary cause of CO_2 emissions but that emissions are significantly reduced by urbanization, the use of renewable energy, and urban concentration. These results highlight how crucial it is to advance sustainable urban design, renewable energy, and energy efficiency to reduce CO2 emissions successfully.

The correlations between CO_2 emissions per capita (CO2) and each independent variable are shown in scatter plots with linear regression lines in Figure 2.

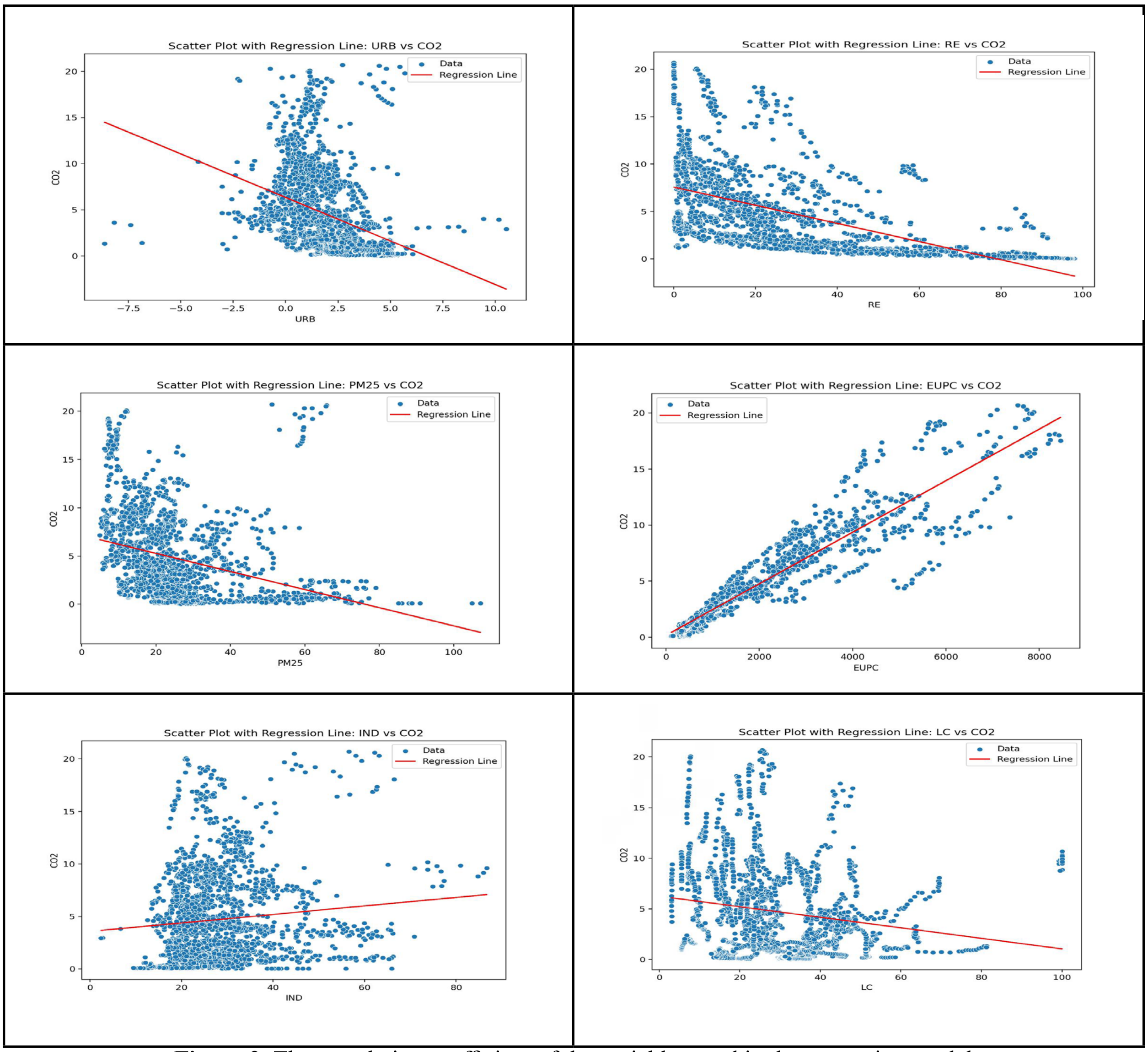

Figure 2. The correlation coefficient of the variables used in the regression model

Overall, the findings support the idea that energy use is the primary factor causing CO_2 emissions and highlight how crucial using renewable energy is to reducing emissions. After researching global trends and analyzing the regression of 107 countries with eight variables, the next decision was to do a correlation analysis of only Kazakhstan with the same eight variables to see if Kazakhstan repeats the global paths (Figure 3).

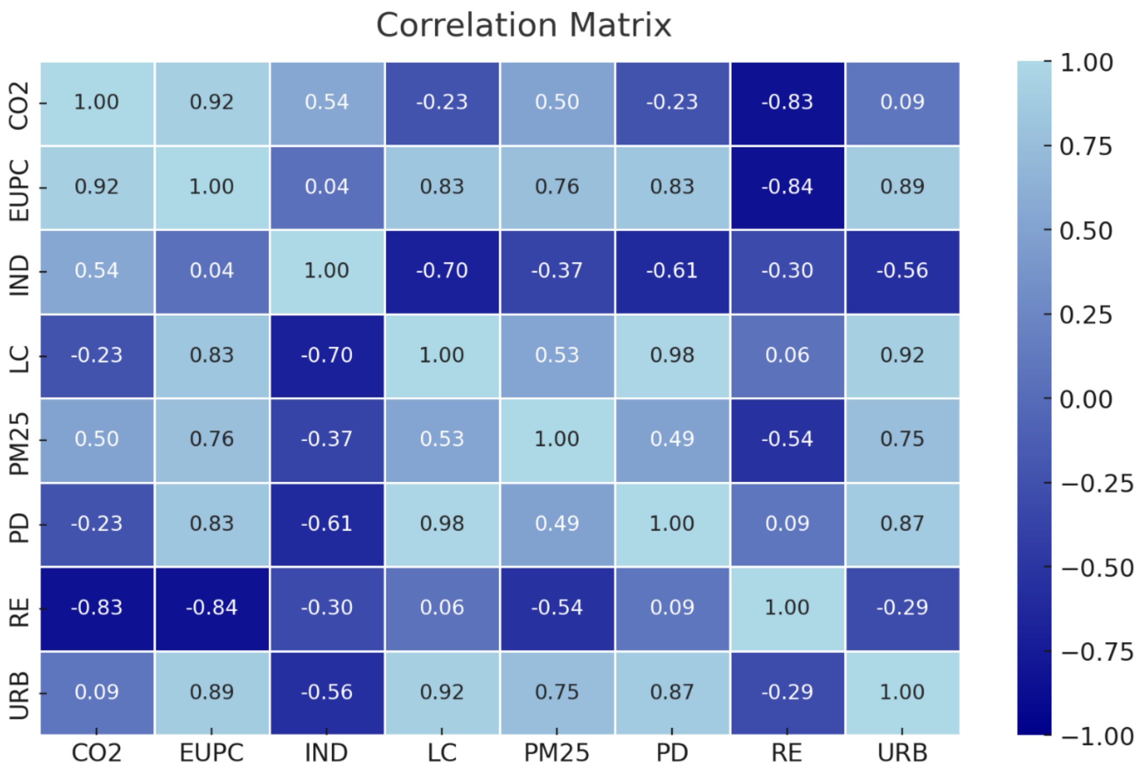

Figure 3. Correlation matrix of Kazakhstan

The matrix shows there is a very strong positive correlation (0.920) between CO2 and EUPC, suggesting that CO2 emissions are driven by higher energy use per capita. Also, it is noticeable that CO2 and RE have a strong negative correlation (-0.830), which indicates that using more renewable energy lowers CO2 emissions. Moreover, the strong positive correlation between EUPC and URB (0.89) indicates that urbanization contributes to increased energy consumption, which leads to higher CO2 emissions. The last most significant finding is the negative correlation (-0.840) between RE and EUPC, which illustrates how renewable energy contributes to lower energy consumption.

Urbanization seems to be associated with lower per capita CO_2 emissions, according to the bivariate linear regression, which is a surprising but important conclusion. Linear regression examines the individual relationship between each independent variable (e.g., URB) and the dependent variable (CO2) without controlling for the influence of other variables. It shows a simple, direct effect. The adverse effect suggests that, on its own, a rise in URB might be linked to a decrease in CO2 emissions. For instance, the adoption of cleaner energy sources or improved infrastructure in urban areas may be indicative of this. This casts doubt on the conventional wisdom that says increased energy use, industrial activity, and transportation requirements inevitably lead to higher emissions as cities grow.

The result of linear regression can be supported by encouraging energy efficiency and public transport use, urbanization can lower CO2 emissions. According to Dodman (2009), compact housing, shorter commutes, and easier access to public transit make dense urban settings frequently more energy-efficient than rural ones. In a similar vein, Glaeser and Kahn (2010) discovered that because of their more energy-efficient infrastructure and decreased reliance on private automobiles, people living in dense cities typically had lower carbon footprints than those in the suburbs.

In Kazakhstan, encouraging the use of renewable energy sources, public transit, and energy-efficient infrastructure could optimise urbanization's ability to reduce per capita CO_2 emissions. Achieving these goals will require investment in sustainable technologies and compact urban planning that reduces urban sprawl. As Dodman (2009) and Wang et al. (2020) point out, the adoption of progressive policies and investments in sustainable urban systems are crucial to the efficiency of urbanization in lowering emissions.

In conclusion, CO2 emissions are not always increased by urbanization. Rather, the quality of urban planning and the incorporation of sustainability concepts into development initiatives determine its environmental impact. A straightforward route to lowering emissions and achieving global climate objectives is provided for Kazakhstan by coordinating urban growth with investments in clean energy and infrastructure.

Wang et al. (2020) stress the importance of compact urban growth and clean energy regulations in lowering emissions in areas with high population densities. Additionally, Guo et al. (2022) provide support, demonstrating that when cities develop and shift to service-based economies, urbanization can result in a decrease in per capita CO_2 emissions. These advantages are especially noticeable in nations with robust environmental laws and carefully designed urban areas.

CONCLUSIONS

This study examined the effects of economic, social, and environmental variables on the relationship between urbanization and CO_2 emissions using data from 107 countries between 2004 and 2023. The findings offer important insights into the dynamics of emissions and urbanization, with significant implications for Kazakhstan's environmental strategies.

Surprisingly, there was a negative correlation between urbanization and CO2 emissions per capita. This calls into question accepted wisdom and emphasises how urbanization may increase energy efficiency, promote compact urban growth, and lower emissions when combined with sensible regulations. These results are consistent with other research that shows that per capita emissions are typically lower in densely populated areas with well-planned infrastructure and access to effective public transit. However, the benefits of urbanization vary depending on the situation and necessitate careful resource management and urban planning.

The biggest percentage of the variation in CO2 emissions was explained by energy consumption per capita, which was found to be the strongest driver of emissions. This emphasises how urgent it is to switch to cleaner energy systems and increase energy efficiency to successfully lower emissions. The adoption of renewable energy has also become a significant mitigating factor, as increasing proportions of renewables significantly reduce CO2 emissions. These findings highlight the significance of incorporating clean energy solutions into national and urban development strategies. Compact populations may benefit from economies of scale in resource utilisation, as seen by population density's small but considerable negative effect on CO_2 emissions. However, the population proportion in the most significant cities had conflicting results, highlighting the difficulties in overseeing energy and infrastructure systems in densely populated urban regions.

The results point to certain policy targets for Kazakhstan to manage urbanization sustainably and lessen its adverse environmental effects. Urban design should prioritise compact, energy-efficient city layouts with integrated public transport networks to reduce reliance on private vehicles and improve resource efficiency. Investments in renewable energy infrastructure are crucial to decarbonize the energy sector and sustainably fulfill the rising urban energy demands. To further cut emissions, stricter energy efficiency regulations for transportation, industry, and buildings should be implemented.

By distributing economic possibilities to smaller urban centers and relieving pressure on large cities' infrastructure, balanced regional development can help address the problems caused by over-concentration in major cities. When efforts to improve air quality and reduce industrial emissions are coupled with public awareness campaigns to promote sustainable lifestyles, environmental sustainability, and economic growth may coexist.

Future research should concentrate on determining the precise circumstances under which urbanization can lower emissions, especially in light of Kazakhstan's distinct environmental and economic difficulties. Critical insights for creating more successful policies will come from research into urban development strategies, technology developments, and governance frameworks. Kazakhstan may attain low-carbon urban expansion that supports its long-term development and climate goals by coordinating urbanization with renewable energy, energy efficiency, and sustainable infrastructure development.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: MB; research design: MB; data collection: MB; analysis and interpretation: MB; writing draft preparation: MB; correction of article: MB; proofread and final approval of article: MB. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy, 38*(1), 656–660. https://doi.org/10.1016/j.enpol.2009.09.002

Bekbossinova, A., & Niyazbekov, A. (2024). The impact of urbanization on air quality in the largest cities of Kazakhstan. *Eurasian Journal of Economic and Business Studies, 68*(3), 66–81. https://doi.org/10.47703/ejebs.v68i3.419

Bekturganova, M. S., & Kireyeva, A. A. (2024). Analyzing the relationship between urbanization and greenhouse gas emissions: The case of Kazakhstan. *Karagandy State University Journal, 3*(115), 47-57. https://doi.org/10.31489/2024Ec3/46-57

Creutzig, F., Jochem, P., Edelenbosch, O., Linus Mattauch, L., Vuuren D., McCollum, D. & Jan Minx, J. (2015). Transport: A roadblock to climate change mitigation? *Science, 350*(6263), 911–912. https://doi.org/10.1126/science.aac8033

Dodman, D. (2009). Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *Environment and Urbanization, 21*(1), 185–201. https://doi.org/10.1177/0956247809103016

Glaeser, E. L., & Kahn, M. E. (2010). The greenness of cities: Carbon dioxide emissions and urban development. *Journal of Urban Economics, 67*(3), 404–418. https://doi.org/10.1016/j.jue.2009.11.006

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics, 110*(2), 353–377. https://doi.org/10.2307/2118443

Guo, F., Zheng, X., Wang, C., & Zhang, L. (2022). Sharing matters: Household and urban economies of scale for a carbon-neutral future. Resources, Conservation and Recycling. https://doi.org/10.1016/j.resconrec.2022.106410

IEA. (2021). Urban energy consumption and greenhouse gas emissions. World Energy Outlook. Retrieved from https://www.iea.org/reports/world-energy-outlook-2021/overview

Liu, H., Wong, W.K., The Cong, P., Nassani, A.A., Haffar, M., & Abu-Rumman, A. (2023). Linkage among Urbanization, energy consumption, economic growth and carbon Emissions. Panel data analysis for China using ARDL model. https://doi.org/10.1016/j.fuel.2022.126122

Raihan, A., & Tuspekova, A. (2022). Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. *World Development Sustainability, 1,* 100019. https://doi.org/10.1016/j.wds.2022.100019

Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D., & Lwasa, S. (2014). Human settlements, infrastructure, and spatial planning. In Climate Change 2014: Mitigation of Climate Change (IPCC Report). Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter12.pdf

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

Shahbaz, M., Loganathan, N., Zeshan, M., & Zaman, K. (2016). Does renewable energy consumption add in economic growth? An application of auto-regressive distributed lag model in Pakistan. *Renewable and Sustainable Energy Reviews, 44*, 1364–0321. https://doi.org/10.1016/j.rser.2015.01.017

Sufyanullah, K., Ahmad, K.A., & Sufyan Ali, M.A. (2022). Does emission of carbon dioxide is impacted by urbanization? An empirical study of urbanization, energy consumption, economic growth and carbon emissions - Using ARDL bound testing approach. *Energy Policy, 164,* 112908. https://doi.org/10.1016/j.enpol.2022.112908

Tleppayev, A., Zeinolla, S., Abishova, S., & Baibussinova, G. (2023). Energy, urbanization, and sustainability indicators: Empirical data from Kazakhstan. International *Journal of Energy Economics and Policy, 13*(1), 154–163. https://doi.org/10.32479/ijeep.13762

UN-Habitat. (2020). World Cities Report 2020: The Value of Sustainable Urbanization. UN-Habitat Report. Retrieved from https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization

Wang, Q., Wu, S., Zeng, Y., & Wu, B. (2016). Exploring the relationship between urbanization, energy consumption, and CO_2 emissions in different provinces of China. *Renewable and Sustainable Energy Reviews, 54,* 1563–1579. https://doi.org/10.1016/j.rser.2015.10.090

Wang, X., Zheng, H., et al. (2019). Kazakhstan's CO_2 emissions in the post-Kyoto Protocol era: Production- and consumption-based analysis. *Journal of Environmental Management, 249,* 109393. https://doi.org/10.1016/j.jenvman.2019.109393

Wang, S., Li, Q., Fang, C., & Zhou, C. (2020). The impact of urbanization on carbon emissions: Panoramic insight from urban agglomerations in China. *Journal of Cleaner Production, 262*, 121288. https://doi.org/10.1016/j.jclepro.2020.121288

Weigert, M., Melnyk, O., Winkler, L., & Raab, J. (2022). Carbon Emissions of Construction Processes on Urban Construction Sites. Sustainability, 14(19), 12947. https://doi.org/10.3390/su141912947

Zhang, C., & Lin, Y. (2012). Panel estimation for urbanization, energy consumption and CO_2 emissions: A regional analysis in China. *Energy Policy, 49*, 488–498. https://doi.org/10.1016/j.enpol.2012.06.048

Information about the author

***Makpal S. Bekturganova –** PhD, Leading Researcher, Institute of Economics CS MSHE RK, Almaty, Kazakhstan, email: maka_91@inbox.ru, ORCID ID: https://orcid.org/0000-0003-1708-8208

Автор туралы мәліметтер

***Бектұрғанова М.С**. – PhD, жетекші ғылыми қызметкер, ҚР БҒМ ҒК Экономика институты, Алматы, Қазақстан, email: maka_91@inbox.ru, ORCID ID: https://orcid.org/0000-0003-1708-8208

Сведения об авторе

***Бектурганова М. С. –** PhD, ведущий научный сотрудник, Институт экономики КН МНВО РК, Алматы, Казахстан, email: maka_91@inbox.ru, ORCID ID: https://orcid.org/0000-0003-1708-8208